(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 541 338 B1

# (12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
**11.09.1996 Bulletin 1996/37**

(51) Int. Cl.[6]: **A61N 1/365**

(21) Application number: **92310071.3**

(22) Date of filing: **03.11.1992**

## (54) Implantable cardiac function monitor and stimulator for diagnosis and therapy delivery

Implantierbares Gerät zur Überwachung und Stimulation des Herzens für Diagnose und Therapie

Appareil implantable de surveillance et de stimulation cardiaque pour diagnostic et thérapie

(84) Designated Contracting States:
**AT BE CH DE DK ES FR GB GR IE IT LI LU MC NL PT SE**

(30) Priority: **04.11.1991 US 787052**

(43) Date of publication of application:
**12.05.1993 Bulletin 1993/19**

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Printed by Rank Xerox (UK) Business Services
2.13.4/3.4

## Description

This invention relates generally to the design of cardiac stimulating devices and, more particularly, to an apparatus that monitors and assesses level of cardiac function then permits a physician to arbitrate the therapy mode, if therapy is indicated. It accomplishes this by assessing impedance, electrocardiogram, and/or pressure measurements, then calculating various cardiac parameters. The results of these calculations determine the mode of therapy to be chosen, then therapy is administered by the device itself.

Patients suffering from chronic congestive heart failure manifest an elevation of left ventricular end-diastolic pressure, according to the well-known heterometric autoregulation principles espoused by Frank and Starling. This may occur while left ventricular end-diastolic volume remains normal due to a decrease in left ventricular compliance concomitant with increased ventricular wall stiffness. Prior attempts to increase wall contractility or to improve cardiac performance have focused on drug therapy and cardiomyostimulation.

Many inotropic drugs have recently become available, targeted at various receptors in the ventricular walls and designed for the purpose of directly stimulating cardiac tissue in order to increase contractility. However, there exist many possible undesirable side effects, in addition to the fact that these drugs do not always work for their intended purpose. This is especially characteristic of the patient suffering from end-stage heart failure. Because of these problems with drug efficacy, the techniques of adaptive rate cardiac pacing and cardiomyostimulation have been developed.

The performance of adaptive rate cardiac pacemakers has advanced greatly in recent years. Such pacers sense the presence or absence of intrinsic cardiac electrical activity, or other physiologic parameter, and then respond only by increasing or supporting heart rate by direct stimulation of cardiac tissue. The heart rate response may also be based on the sensing of some type of physiologic need but, to date, no implantable device has been proposed to directly evaluate cardiac function and then deliver appropriate therapy designed to improve function. Although adaptive rate pacing may increase cardiac output by increasing heart rate, it has not been indicated as a therapy in heart failure because neither contraction nor relaxation are improved, and conversely, increased myocardial oxygen demands may ensue. The only application of pacing technology to address heart failure has been in the area of cardiomyoplasty, where electrical stimulation is directed towards some type of skeletal muscle system to augment cardiac function.

Cardiomyostimulation is a technique intended to increase cardiac output, in order to assist a compromised heart. As disclosed in U.S. Patent No. 4,735,205, issued to Chachques, skeletal muscle can be trained to withstand the rigor of long-term sequential contraction without undue fatigue. When such trained muscle is surgically wrapped around the ventricles then sequentially electrically stimulated using demand-type cardiac pacer circuitry, mechanical assistance is provided for compromised contraction. This occurs because stimulated contraction of this skeletal muscle causes constriction upon the ventricles and forces blood into the arterial system. Although this process has proven to be useful, it does not directly affect contractile forces within the heart itself and is known to impair diastolic function by increasing ventricular chamber "stiffness". Hence, this process does not increase wall contractility.

Despite the improvements in treatment described above, there remains a large group of patients for whom these approaches either do not work or are contraindicated for other medical reasons. The present invention is intended to enhance contractility or relaxation in this group of patients by providing an apparatus that monitors cardiac function and then directly stimulates ventricular tissue in a way that optimizes the functional parameter or parameters under control.

Impedance-based measurements of cardiac parameters such as stroke volume are known in the art. U.S. Patent No. 4,674,518, issued to Salo, discloses an impedance catheter having plural pairs of spaced surface electrodes driven by a corresponding plurality of electrical signals comprising high frequency carrier signals. The carrier signals are modulated by the tidal flow of blood in and out of the ventricle. Raw signals are demodulated, converted to digital, then processed to obtain an extrapolated impedance value. When this value is divided into the product of blood resistivity times the square of the distance between the pairs of spaced electrodes, the result is a measure of blood volume held within the ventricle. These calculations may be made using spaced sensors placed within a catheter, as in the Salo '518 patent, or they may be derived from signals originating in electrodes disposed in the heart, as described in U.S. Patent No. 4,686,987, issued to Salo and Pederson. The device of the '987 patent senses changes in impedance to determine either ventricular volume or stroke volume (volume of blood expelled from the ventricle during a single beat) to produce a rate control signal that can be injected into the timing circuit of another device, such as a cardiac pacer or drug infusion pump. In this manner, the rate of operation of the slaved device may be controlled. An example of application of this impedance sensing circuitry to a demand-type cardiac pacer is disclosed in U.S. Patent No. 4,773,401, issued to Citak, et al. Other devices may combine impedance sensing with internal pressure measurement as disclosed in EP-A-0 449 401 of Salo, and with telemetry as disclosed in U.S. Patent No. 4,562,841, issued to Brockway, et al.

US-A-4,541,417 relates to a coranary augmentor which includes stimulating means for repetitively applying to the patient a stimulating current. The current is sized to involuntarily contract and relax at least one muscle. The body responds to this involuntary exercise to produce catecholamines which when induced into cir-

culation increase the strength of contraction of the myocardia during left ventricular contraction.

US-A-5042497 discloses an apparatus for the prediction of arrhythmia in a patient. The apparatus includes sensing means for sensing ECG signals and means for monitoring the derivative of volume or pressure changes in the patient's heart as an indication of neural tone. In response to altered neural tone, the apparatus either paces the heart or applies a defibrillating shock. Alternatively, a drug can be applied to the patient's heart or the patient can be alerted to seek medical attention.

According to the present invnetion there is provided apparatus, preferably implantable, for applying therapy to a patient as claimed in claim 1.

The present invention provides a device that detects and monitors levels of cardiac function based on the hemodynamic indicators of the contracted state of the heart and delivers therapy on the basis of this monitored information. The therapy includes direct electrical stimulation, resulting in improved strength of heart contractility.

The apparatus of the present invention enhances either systolic or diastolic cardiac function.

It is an object to deliver therapy to augment or improve cardiac hemodynamic parameters.

It is another object to implement various electrical stimulation modalities to enhance a heart's contractile state, i.e. enhancement of contractile strength.

Monitoring of pressure and/or impedance can be used to assess short or long-term changes in level of cardiac function. Preferably, conventional parameters of cardiac function and contractile state are monitored, including all phases of the cardiac cycle. Thus, assessments of measured contractile state include indices of both cardiac relaxation and contraction. Utilizing the dual source ventricular impedance plethysmography technique described in U.S. Patent No. 4,674,518, issued to Salo, a preferred embodiment of the apparatus monitors cardiac function by assessing hemodynamic changes in ventricular filling and ejection or by calculating isovolumic phase indices by known algorithms. The primary calculations involve:

(1) the time rate of change in pressure or volume, dP/dt or dV/dt, as isovolumic indicators of contractility;

(2) ejection fraction as an ejection phase index of cardiac function according to the known quotient of stroke volume divided by end diastolic volume;

(3) Maximal elastance, $E_{MAX}$,

(4) regression slope through maximal pressure-volume points as a further ejection phase index of contractility using the method of Sagawa;

(5) stroke work according to the known pressure-volume integration;

(6) the time course of minimum (end) diastolic pressure-volume measurements according to the method of Glantz as a measure of diastolic function; and

(7) cardiac output calculation according to the known product of heart rate and stroke volume as an index of level of global function.

To accomplish these calculations, some necessary values may be pre-stored in an auxiliary memory as criteria ranges or as input patient baseline data.

## BRIEF DESCRIPTION OF THE DRAWING FIGURES

These together with other objects and advantages, which will become subsequently apparent reside in the details of construction and operation of a preferred embodiment, as more fully hereinafter described and claimed, reference being had to the accompanying drawings forming a part hereof, wherein like numerals refer to like parts throughout.

FIGURE 1 is a functional block diagram of a preferred apparatus for implementing the present invention;

FIGURE 2 shows placement of multiple sensors within the right ventricle of the heart and a block diagram of the signal processing circuitry used in practicing the invention;

FIGURE 3 is a diagram illustrating the "logic device" section of Figures 1 and 2; and

FIGURE 4 is a diagram illustrating the "therapy" section of Figure 1, and including parts (226-240) which are not according to the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Figure 1, a preferred embodiment of the stimulating apparatus incorporating the present invention is shown by means of a block diagram. It is comprised of intracardiac sensing apparatus, denoted generally as 10, hemodynamic signal processing means 20 coupled to the sensing apparatus, a logic device 60 and a physician selectable therapy mode means, denoted generally as block 120.

The sensing apparatus 10 and associated circuitry shown in Figure 2 may be similar to the systems disclosed in U.S. Patent No. 4,674,518, issued to Salo; U.S. Patent No. 4,686,987, issued to Salo, et al.; and EP-A-0 449 401 to Salo, et al.; all assigned to Applicant's assignee. As such, it comprises intracardiac sensing means 12 and associated drive circuitry 20. A plurality of electrodes placed in or on the heart are used to derive impedance signals. In addition, or alternatively,

sensing and drive circuitry for a piezoelectric transducer may be used to derive pressure versus time signals, as described in detail hereafter.

The signal sensing and processing unit 20 (Figure 1), receives the raw hemodynamic signal from the sensing/stimulating lead apparatus 12 and contains amplification, filtering and demodulation circuitry. The resulting signals appear as waveforms of impedance versus time, pressure versus time or as standard electrocardiography PQRST waveforms. This signal is forwarded to logic circuitry (Block 60) for further processing, as also described in greater detail hereinafter.

The logic device 60, may comprise a microprocessor of conventional design having data storage means, an arithmetic/logic unit and an A/D converter, which operate under control of a stored program. It receives the filtered and demodulated signals from the sense unit 20 via lines 30 and 50 (Figure 2), then processes them in a manner that is a combination of the methods disclosed in the aforereferenced EP-A-0 449 401 and U.S. Patents 4,674,518 and 4,686,987. Logic device 66 includes a memory (Figure 3) for storing baseline values and references relating to cardiac function criteria. Also stored for reference by the microprocessor are patient baseline data that are sampled at various intervals. Physician inputs to the microprocessor via a keyboard or the like are used to manually select a mode of therapy, as indicated by block 120.

The various therapies available, as represented generally by block 130 for pacing, 140 for skeletal muscle stimulation and 160 for telemetry, are all described more fully hereinafter. These include the adoption of various cardiac pacing modes (Block 134), skeletal muscle stimulation (Blocks 142 and 144) and externally provided therapies directed from the implanted device via telemetry apparatus (Blocks 162, 164 and 166). All are focused upon improving function of the heart by means of selective timing of electrical stimuli to the myocardium or other tissue, or by the automatic infusion of an appropriate drug. This is in contrast to conventional cardiac pacing which typically senses the absence of intrinsic cardiac activity and simply stimulates the occurrence of a contraction, or standard rate-adaptive pacing systems which monitor independent non-cardiac variables in order to provide some rate response to exercise. These various therapies are either administered through the same internal lead that sensed the original signal or are administered via auxiliary electrodes placed on the heart or other muscle or via external systems that receive a signal telemetered to them by the implantable device of the present invention.

Turning to the elements of Figure 1 with greater particularity, the sense apparatus and circuitry 10 is based upon an impedance plethysmography technique, such as that disclosed in the aforereferenced Salo 4,674,518 and Salo, et al. 4,686,987 patents. These techniques utilize measurement of intracardiac impedance, specifically, measurement of impedance in the right ventricle. An intracardiac impedance waveform containing information relating to stroke volume as well as to frequency and depth of respiration is obtained from a set of electrodes, designated generally as 12, and which are disposed on the surface of a catheter or lead 14 and connected by conductors within the lead body to the signal processing circuitry 20.

Shown in greater detail in Figure 2 and as disclosed in our earlier Patent 4,686,987, the catheter or lead 14 is intended to be inserted into the right ventricle of the heart. One possible electrode configuration is shown as being mounted to the surface of this lead 14, where, for example, a pair of drive electrodes 11 and 21 and a pair of sense electrodes 13 and 15 are shown connected to signal processing means 20 by the conductors generally designated as 32. Electrical conductors 34 and 36 couple the drive electrodes 11 and 21 to a carrier oscillator circuit 38 contained in signal processor 20. Electrical conductors 40 and 42 couple the sense electrodes 13 and 15 to a sensing amplifier 46, also contained in signal processor 20. A filter and demodulator circuit 48 receives the signal from the sense amplifier 46 and contains circuitry to amplify, filter and demodulate the signal before further processing by the logic device (Block 60). The circuitry at block 48 creates a time-dependent signal proportional to intracardiac impedance (Z v. t) on line 70. It is then in proper form for processing in accordance with the algorithms defined by the programs contained in the logic device (Block 60). To provide electrical stimulation, there is provided a pulse generator 150 whose output is connected by conductor 44 in the catheter 14 to the stimulating tip electrode 11.

The technique of the present invention may also utilize a pressure sensitive, solid-state pressure transducer 17 positioned near the distal end of an endocardial lead 14 to directly monitor hemodynamic changes, such as variation in pressure within the right ventricle. Utilizing methods known in the art, a pressure versus time signal (P v. t) is obtained on line 80, which reveals excursions due to normal systolic and diastolic pressure variations, and which are contaminated by low frequency variations which correspond to intrathoracic pressure changes attendant to normal respiratory processes. As explained in the Salo, et al. EP-A-0 449 401, a clean signal may be obtained by using a signal processing means 58 which provides pressure variations on a beat-by-beat basis. Appropriate filtering is used to extract the period of the respiratory signal and its peak-to-peak amplitude (tidal volume).

Specifically, a commercially available miniature pressure transducer 17 is mounted within the endocardial lead 14. Such a pressure transducer typically comprises a chemically etched silicon diaphragm onto which a piezoelectric resistive crystal has been mounted. Wiring connects the crystal transducer to external circuitry for processing the pressure modulated carrier signal. For protection, this transducer 17 is typically mounted behind a compliant membrane which covers a window opening 19. The window 19 is positioned near the distal end of the endocardial lead 14.

Mechanical variations in pressure within the ventricle are monitored and converted into electrical signals which depict the amplitude changes of the pressure waves advancing toward the transducer head. This may be accomplished by a simple Wheatstone bridge circuit or other known circuitry. Within the pressure signal processing apparatus (Figure 2), a low duty cycle pulse generator 53 sends pulsatile alternating current toward the transducer head via conductors 52. The signal from the energized crystal (not shown) is then carried via conductors 54 to amplifier 56. The signal processing circuit 58 receives the signal from the amplifier 56 and contains circuitry to filter and demodulate the signal to create a time-dependent signal proportional to intracardiac pressure. After such extraction of the modulation envelope and removal of the carrier, the microprocessor-based logic device (Block 60), shown in detail in Figure 3, receives the signal on line 80, which then is in proper form for processing.

Turning to the block diagram of Figure 3, the parallel manner in which the Z v. t and P v. t waveforms are processed within logic device 60 becomes evident. These processes, as well as processing of the electrocardiogram signal (Block 62), are described in detail in U.S. Patent Nos. 4,674,518 (Salo), 4,686,987 (Salo, et al.) and 4,773,401 (Citak, et al.) as well as in EP-A-0 449 401 (Salo). Application of the electrocardiogram signal (Block 62) to a peak-to-peak detector (Block 64) yields a signal that is proportional to heart rate (HR) at block 66. Application of the Z v. t signal (Block 70) to a peak-to-peak detector (Block 72) yields a signal that is proportional to the heart's stroke volume (SV) per beat at block 74. Application of the P v. t signal, as at block 80, to a peak-to-peak detector (Block 82) yields a signal at block 84 that is proportional to the change in pressure ($\Delta P$) that occurs as the heart beats. From the buffers providing the HR (Block 66) and SO (Block 74) data, cardiac output (CO) can be calculated as the product of HR x SV, as indicated by block 76. This value is useful as an index of global function, relating to performance of the entire heart as a unit, as opposed to the regional function of, for example, one ventricle.

Differentiator and peak detector circuits, as at blocks 90 and 92, produce signals that are proportional to the positive or negative peak value of the differentiated waveform, whether impedance, volume or pressure (Lines 94, 96, 98). These measures are known indices of systolic or diastolic function.

Further calculation of ejection fraction and stroke work may also be performed at this stage by a microprocessor (Block 110). A conventional input/output (I/O) device (Block 100) receives the HR (Block 66), SV (Block 74), CO (Block 76), $\Delta P$ (Block 84), dZ/dt (Line 94), dV/dt (Line 96) and dP/dt (Line 98) signals for storage in memory devices 104 using RAM 106 or ROM 108, or for further processing in microprocessor 110. Ejection fraction (EF) is computed by dividing the stroke volume (SV) signal (Block 74) by end-diastolic volume (EDV). Stroke work (SW) is derived by integrating the area within the curve defined by a plot of pressure v. volume as the heart contracts and expands. A further ejection phase index of contractility may be derived from the slope of a regression line passing through maximal pressure-volume points that are plotted for sequential beats, which yields a characteristic end-systolic pressure-volume relation that may be compared to desirable known ranges. Alternatively, the stroke work may be plotted against end diastolic volume and the slope of the linear regression used as a measure of systolic function. This measures "preload recruitable stroke work" (PRSW) and is discussed by Glower, et al. (Circulation 71(5): 994-1009, (1985)). The relationship of end-diastolic pressure to volume is also useful, as an index of diastolic function, when compared to an optimal range. This assessment involves fitting the plot of minimum diastolic pressure against end-diastolic volume to a power function.

The signals derived from this processing are used in combination, within the therapy options selected by the physician as explained below.

Once a therapy has been selected by a physician and a particular program stored in the ROM 108 for executing the selected algorithm is activated to increase the strength of ventricular contractions of the heart, the signal is gauged to initiate or continue the appropriate therapy. Therapy includes various ways of energizing the stimulation pulse generator 150. With some form of cardiac pacing selected (Block 130), appropriate mode and rate control algorithms are activated (Block 132) and pacing pulse patterns are delivered to the heart via pulse generator 150. Energizing the pulse generator can be selected to stimulate cardiac tissue in a variety of ways (135, 136, 137, 138). Furthermore, skeletal muscle can be stimulated (Block 140), utilizing a sequential mode. Through a telemetry link, an external drug infusion system 166 can be activated to inject a prescribed dose of a desired medicament into the patient.

As indicated immediately above, several pacing modes are available. These include paired pacing 135, biventricular pacing 136, burst stimulation 137 or intercalated pacing 138. All are focused upon achieving the end result of increasing contractile response of the heart by selective sequencing of stimuli, rather than simply functioning as a cardiac pacemaker by appropriately timing when an intrinsic beat should occur and providing it when such a beat is absent.

The present invention also contemplates that pulse generator 150 may be a dual chamber device. An example of a pacer that may be used in the present invention is provided in U.S. Patent No. 4,928,688, issued to Mower and assigned to Applicant's assignee. In this pacer, conventional demand pacing circuitry is interconnected to biventricular control circuitry in order to deliver stimuli at two different sites in response to sensed changes in cardiac function for the purpose of augmenting contractile forces of the myocardium. The stimulating pacing pulses are deliverable simultaneously.

Although directed to control of a demand-type pacer, an example of a control parameter that may be used to supplement the present invention is provided in U.S. Patent No. 4,773,401, issued to Citak, et al. The Citak, et al. disclosure reveals demand-type circuitry that utilizes as a control parameter the time interval between a systole marker (native QRS or paced beat) and the positive inflection point of the Z v. t signal.

A conventional multielectrode impedance pacing lead, as known in the art, may be used to deliver appropriate pulses to the heart. When selected as the pacing mode, paired pacing (Block 135) will be expected to increase contractile function of the heart, provided the delay between stimuli is appropriately chosen. In this mode, an intrinsic or a paced beat is sensed, then an interval of 150-200 msec is timed before a pacing pulse is delivered to the wall of the right ventricle.

The lead arrangement required for biventricular pacing (Block 136) differs from typical pacer leads. Two lead segments are required, each of which has a stimulation tip electrode for pacing and appropriate sensing electrode(s). One is inserted into the right ventricle, preferably through the superior vena cava, while the second is preferably inserted through the coronary sinus (or into the left ventricle), as described in greater detail in the aforereferenced Mower patent. To augment detection capabilities of the control circuit, it is also preferred to position atrial sense electrodes appropriately. In this manner, the control circuit can refer to both atrial and ventricular depolarizations that are present or absent and respond appropriately through a preset A-V delay timer.

An alternative pacing mode is burst stimulation (Block 137). This technique increases the strength of a myocardial contraction episode via delivery of 1 to 12 stimulating pulses at a frequency of 10 to 130 Hz to a single pacing site or to multiple sites. An example of application of this mode of pacing is disclosed in U.S. Patent No. 4,865,036, issued to Chirife.

Intercalated pacing (Block 138) is another alternative. In this technique, contractile function of the heart wall is enhanced by extending the relaxation period between beats. In pathologic asynchronous conditions, such as atrial fibrillation, the sequential conduction pattern which exists in individual muscle fibers may be disrupted by delivery of a conducted beat followed by delivery of extrastimuli to the right ventricle at predetermined intervals. Such potentiation functions to extend the relaxation period between beats. A delay means 132 calculates a delay of a preset interval after the presence of a conducted heartbeat is indicated.

A further rate control algorithm stored in the ROM 108 of microprocessor 110 is utilized to stimulate skeletal muscle (Block 140) using the burst stimulation mode described above. Depending upon the therapeutic rationale implemented, skeletal muscle may be surgically wrapped around the ventricles (Block 142) then stimulated to contract sequentially, as in the manner disclosed in U.S. Patent No. 4,735,205, issued to Chachques. Skeletal muscle may alternatively be surgically wrapped around an artificial bladder (Block 144), such as an apicoaortic conduit pouch as described by Acker, et al., (J. Thoracic CV Surgery 94:163-74 (1987)). Alternatively, it may be applied to an extra-aortic balloon pump as disclosed by Chiu, et al. (J. Thoracic CV Surgery 94:694-701 (1987)). In another approach, it may be applied to skeletal muscle tube ventricles or pouches, as described by Stevens, et al. (J. Surg. Res. 46: 84-89 (1989)).

To condition the skeletal muscle for these applications, synchronization between intrinsic or paced heart activity and skeletal stimulation is programmable from 1:1 to 8:1. The skeletal stimulation consists of a pulse train of 1-12 pulses at a frequency of 10-128 Hz in which spacing between individual pulses can be decremented to increase in frequency as the burst progresses. Programmable "therapy bands" with independent synchrony and delay settings are available to correspond to four different heart rate levels.

By monitoring either systolic or diastolic parameters of the natural or artificial ventricle, as previously described, it is possible to optimize both the rate and mode of stimulation. Since patients requiring these drastic interventions are generally in advanced cardiac failure, their cardiac function is marginal at best and exhibits increased sensitivity to external perturbations (i.e. loading, as in ventricular preload or afterload, etc.). Even though the actual improvement in cardiac function may be small, these patients exist in such a delicate balance that a small improvement in cardiac output can result in a dramatic improvement in the patient's clinical condition.

Cardiac parameters calculated from the implantable device may be transmitted, via telemetry, to provide control to an external drug monitor system.

The telemetry feature of the present invention may utilize a radio frequency data link, as described in the Brockway 4,562,841 patent or other established approaches now used in the cardiac pacing field. Encoding/decoding circuitry is contained in both an external programmer and in the implantable device. Essentially, symmetric transmission pulses of radio frequency signals in the 100 kHz frequency range are exchanged between these two devices, then formatted into proper sequence and interpreted by I/O controller circuitry. The decoded information is used to modify therapy, in the case of an external drug pump (Block 164).

A drug infusion system (Block 166) is disclosed in U.S. Patent No. 4,529,401, issued to Leslie and assigned to Applicant's assignee. A microprocessor receives a signal from a telemetry input circuit and uses the decoded information to control an infusion pump.

The external infusion pump employed is preferably programmable and operates to supply a desired dosage of medicament to a patient in accordance with a desired time profile. It contains encoding/decoding and I/O circuitry to enable receipt and transmission of radio fre-

quency signals via the telemetry circuits employed in the implanted portion.

Those skilled in the art will recognize that the apparatus reflected by the block diagrams of Figures 1, 2 and 3 may be implemented using all analog circuitry or, alternatively, by incorporating an analog-to-digital converter at the output of the filter and demodulation circuits 48 and 58, the circuits downstream from such an A/D converter can readily be implemented in a programmed microprocessor or microcontroller architecture.

In operation, the physician will evaluate therapy options based on the patient's history and diagnostic workup, including catheterization, electrophysiology, stress testing or other reports. Once a decision is made to implant the apparatus of the present invention, suitable leads will be selected and the pulse generator (where appropriate) of the apparatus will be programmed to activate those parameters which are particularly applicable to the individual patient. The apparatus will then be implanted and the sensing lead positioned according to the intended application. At this time, external standards are used to validate the measurements calculated by the device and the selected therapy or therapies will be preliminarily tested. If more than one therapy mode is found to be effective, the physician can elect to establish a decision tree in which alternate modes may be selected to respond to specific ranges of the calculated physiologic values. Alternatively, if a graded response is obtained at different levels of the delivered therapy, an additional decision tree is available to increase or decrease administration of the therapy when the monitored parameters stray from the preset ranges. For example, if increasing the level of pacing output was found to result in a proportional improvement in contraction, it may be desirable to program different levels of output which will be activated as different levels of physiologic need are detected. The testing performed at the time of implant aids the physician in determining these ranges. Thus, criteria for the changes in output and the types of changes to be monitored, in addition to baseline measurements of the selected parameters, are measured and stored in the device's memory 104 at the time of implant. These preprogrammed parameters are treated as baseline measurements during comparisons to subsequently measured parameters. The RAM memory 106 included in microprocessor 110 includes the capability of accumulating functional data over time. As with cardiac pacemakers, acute physiological changes, such as normal responses to stress or exertion, are preprogrammed as transient episodes which fall within specified ranges of cardiac parameters to evoke predetermined levels of therapy.

Figure 4 provides a functional block diagram which more fully discloses the therapy selection algorithm represented by block 120 of Figures 1 and 3. Referring to block 200, a mode of therapy is externally determined by a physician on the basis of the patient's history and prior diagnostic testing then initiated along with preprogrammed parameter ranges at the time of implant. When a mode of therapy is selected, the device is activated, as at block 202. Upon initiation of therapy, the device begins to monitor the preselected parameters (Block 204) which provide an index of cardiac function. Instantaneous values for these parameters are compared at 206 to predetermined stored values representing desired ranges. Based upon individual preset ranges and levels entered by the physician at block 200, it may be desirable to store the instantaneous values obtained at block 204 as data, as at line 208 and block 210. This data may be in the form of individual values calculated by logic device 60 and microprocessor 110, or accumulated functional data, such as selective samples of electrocardiograms. Under some conditions entered at block 200, it is desirable to monitor and store the calculated parameters at predetermined time intervals (Block 212). When long term monitoring is desirable, as indicated at line 214 and block 216, the function monitor/stimulator will be programmed to periodically reset. When such monitoring is not desired, as at line 218, the function monitor/stimulator is programmed to assess whether to continue therapy (Block 220) based upon criteria input prior to implant (Block 200). Alternatively, when calculated values are compared to preset ranges and values (Block 206), there may be no need at this point to store data, as indicated at line 222. Thus, the function monitor/stimulator is programmed to immediately assess whether to continue therapy (Block 220) based upon criteria input prior to implant (Block 200). If the instantaneous value previously calculated at block 204 falls within the preset parameters, the function monitor/stimulator is preprogrammed to return to monitor mode (Block 204), as indicated at line 224. When the calculated value does not fall within a preset range or parameter, as indicated at line 226, the physician will be alerted, as indicated at block 228 and not in accordance with the present invention. This may be accomplished in a variety of ways available to one skilled in the art, among which a telemetered signal to a printer unit 164 is preferred. In response to the physician alert at block 228 and not in accordance with the present invention, the physician may desire to enter an adjustment in therapy (Line 230) or maintain the present preprogrammed criteria (Line 232). When an adjustment in therapy criteria is desired, the physician will initiate an appropriate response as at block 234. The physician may choose to increase the present mode of therapy (Block 236), decrease the present mode of therapy (Block 238) or he may desire to activate a different mode of therapy (Block 240). Regardless of which option is selected, at this time it may be desirable to store the calculated instantaneous values as data (Block 242). Whether stored (Line 244) or not stored (Line 246), the function monitor/stimulator is preprogrammed to be reset by returning to block 204 to monitor all presently preselected parameters. As indicated at blocks 248 and 256, the function monitor/stimulator is also preprogrammed to assess

whether a long-term monitor mode was activated by the physician at block 234. If this mode is selected, as indicated at line 250 and block 252 or line 258 and block 216, instantaneous values of cardiac function parameters will be intermittently sampled according to a preprogrammed algorithm. If this mode is not activated, as indicated at lines 254 or 260, the function monitor/stimulator is programmed to reset to monitor cardiac function (Block 204) in the presently programmed manner.

## Claims

1. Apparatus for applying therapy to a patient for treatment of chronic heart failure affecting wall stiffness to improve wall contraction or relaxation, the therapy being based upon the contractile state, as indicated by the levels of ventricular end-diastolic volume and pressure of said patient's heart, characterised in that the apparatus comprises :-

   (a) intracardiac sensing means (10) for sensing hemodynamic indicators of contractile state in at least one ventricular chamber of the heart, said hemodynamic indicators including (76) a measurement of the cardiac output of the heart;
   (b) signal means (20,60) coupled to said sensing means (10) for developing a control signal in response to said hemodynamic indicators;
   (c) patient therapy means (120,130,140), including electrical therapy means having at least one stimulating electrode (11) for applying stimulating pulses to the heart tissue in response to said control signal, within predetermined therapy options selected by a physician, to increase the strength of contraction of the patient's heart so that during contraction the cardiac output is increased; and
   (d) application means (60) coupled to the patient therapy means (120,130,140) and to the signal means (20,60) for applying said control signal to said patient therapy means (120,130,140), for changing said contractile state by increasing the strength of contraction of the heart.

2. Apparatus for applying therapy to a patient as claimed in claim 1, characterised in that :

   the therapy means includes a drug infusion system (166) for administering a drug to the patient as a function of said control signal to increase the strength of contraction of the patient's heart.

3. Apparatus as in Claim 1 or 2, wherein said intracardiac sensing means includes pressure sensing means (17) operable to sense the pressure in at least one ventricular chamber of the heart and said signal means (20,60) is operable to develop a pressure control signal varying as a function of said pressure due to the beating action of the heart, said application means being operable to apply said pressure control signal to said patient therapy means (130,140,166) for changing said contractile state by increasing the strength of contraction of the heart.

4. Apparatus as in Claim 1, 2 or 3, wherein said intracardiac sensing means includes intercardiac impedence sensing means (13,15) operable to sense ventricular volume in at least one ventricular chamber of the heart; said signal means (20,60) being operable to develop a volume control signal varying as a function of said ventricular volume; and said application means being operable to apply said volume control signal to said patient therapy means for changing said contractile state by increasing the strength of contraction of the heart.

5. The apparatus as in Claim 4, wherein said signal means (20,60) includes means (110) operable to calculate an ejection fraction, said signal means being operable to develop a control signal varying as a function of said ejection fraction, said application means (60) being further operable to apply to said patient therapy means (130,140), said control signal that varies as a function of ejection fraction, wherein ejection fraction is computed by dividing a control signal value selected to indicate stroke volume by a control signal value selected to indicate end-diastolic volume.

6. The apparatus as in Claim 4, wherein said sensing means (10) is operable to sense heart rate, said signal means (20,60) including means (64,72,76) for calculating cardiac output, said signal means being operable to develop a control signal varying as a function of said cardiac output, said application means (60) being operable to apply to said patient therapy means or drug infusion system, said control signal that varies as a function of cardiac output, wherein cardiac output is calculated as the product of a control signal value selected to indicate sensed heart rate times a control signal value selected to indicate stroke volume.

7. The device as in Claim 3, wherein said signal means (20,60) includes means (58) for producing a time varying signal proportional to pressure measured in one cardiac chamber due to the beating action of the heart; means (58) for extracting from said time varying signal a modulation signal due to pressure changes in said cardiac chamber; said signal means (20,60) being operable to develop said pressure control signal from said modulation signal.

8. The device as in Claim 4, wherein said signal means (20,60) includes means (48) for producing a

time varying signal proportional to impedance measured in one cardiac chamber due to beating action of the heart; means (48) for extracting from said time varying signal a modulation signal due to impedance changes in said cardiac chamber; said signal means (20,60) being operable to produce an impedance control signal from said modulation signal and said application means being operable to apply said impedance control signal to said patient therapy means (130,140,166) for changing said contractile state by increasing the strength of contraction of the heart.

9. The device as in Claim 4 when dependent from Claim 3, wherein said signal means (20,60) includes a microprocessor (110) for computing the area inside a curve obtained by integration of a plot of the pressure as a function of the ventricular volume, as an indicator of stroke work; said signal means being operable to develop a stroke work control signal varying as a function of the stroke work indicator; and said application means being operable to apply said stroke work control signal to said patient therapy means (130,140,166), for changing said contractile state.

10. The device as in Claim 4, when dependent from Claim 3, wherein said signal means (20,60) includes a microprocessor (110) for computing the slope of a regression line plotted through maximal pressure/volume points taken at end-systole of the cardiac cycle, as an indicator of ejection phase contractility; said signal means being operable to develop an ejection phase control signal varying as a function of the indicator of ejection phase contractility; and said application means being operable to apply said ejection phase control signal to said patient therapy means (130,140,166), for changing said contractile state.

11. The device as in Claim 4 when dependent from Claim 3, wherein said signal means includes a microprocessor (110) for computing a curve resulting from a plot of minimum diastolic pressure against end-diastolic volume, as an indicator of diastolic function; said signal means being operable to develop a diastolic function control signal varying as a function of said curve; and said application means being operable to apply said diastolic function control signal to said patient therapy means (130,140,166), for changing said contractile state.

12. The device as in Claim 1 wherein said patient therapy means further includes means (132,135) for applying said stimulating pulses from said electrode (11) to the heart in a predetermined pattern for increasing the strength of contraction of said heart, wherein said predetermined pattern of stimulating pulses includes a pair of pulses, said pair comprising delivery of a first pulse that is either intrinsic or paced, followed by a delay in a range of 140 to 200 msec, then delivery of a second pulse in the form of a pacing pulse, deliverable to the right ventricle of the heart, to increase the strength of contraction of said heart.

13. The device as in Claim 1, wherein said patient therapy means further includes means (132,136) for applying said stimulating pulses from said stimulating electrode (11) to the heart in a predetermined pattern for increasing the strength of contraction of said heart, wherein said predetermined pattern is a pattern of stimulating pacing pulses deliverable to chambers of the heart.

14. The device of Claim 13, wherein said pacing pulses are deliverable simultaneously.

15. The device of Claim 13 or 14, wherein said pattern is biventricular.

16. The device as in Claim 1 wherein said patient therapy means further includes means (132,137) for applying said stimulating pulses from said stimulating electrode (11) to at least one site in the heart in a predetermined pattern for increasing the strength of contraction of said heart, wherein said predetermined pattern of said stimulating pulses includes a burst pattern, said burst pattern including delivering from 1 to 12 stimulating pulses at a frequency in the range of from 10 to 130 Hz.

17. The device as in Claim 1 wherein said patient therapy means further includes means (132,138) for applying said stimulating pulses from said stimulating electrode (11) to the heart in a predetermined pattern for increasing the strength of contraction of said heart, wherein said predetermined pattern of said stimulating pulses includes a pattern of intercalated pacing, comprising at least one extrastimulus deliverable to the right ventricle; a delay means (132) for calculating a delay of a preset interval after said control signal indicates the presence of a conducted heartbeat; and means (132) for developing a control signal for causing said patient therapy means to deliver at least one extrastimulus to the right ventricle, thereby extending a relaxation period between beats of the heart to enhance the strength of contraction of said heart.

18. The device as in Claim 1 wherein said patient therapy means further includes skeletal muscle stimulating means (140) for applying a predetermined pattern of said stimulating pulses from said stimulating electrode (11) to a skeletal muscle (142) that has been surgically attached to the heart, for increasing the strength of contraction of said heart.

19. The device as in Claim 1 or 2, wherein said means for applying said control signal to said patient therapy means (130,140) further includes telemetry means (160) for transmitting and receiving radio frequency encoded signals.

**Patentansprüche**

1. Vorrichtung zum Anwenden einer Therapie bei einem Patienten zur Behandlung eines chronischen Herzfehlers, welcher die Wandsteifheit beeinflußt, um die Wandkontraktion oder -entspannung zu verbessern, wobei die Therapie auf dem kontraktilen Zustand basiert, wie er durch die Niveaus des ventrikulären enddiastolischen Volumens und Drucks des Herzens des Patienten angegeben wird, **dadurch gekennzeichnet**, daß die Vorrichtung umfaßt:

   (a) eine intrakardiale Abtasteinrichtung (10) zum Abtasten hämodynamischer Indikatoren des kontraktilen Zustandes in wenigstens einer ventrikulären Kammer des Herzens, wobei die hämodynamischen Indikatoren eine (76) Messung der Herzleistung des Herzens umfassen,
   (b) eine Signaleinrichtung (20, 60), die mit der Abtasteinrichtung (10) gekoppelt ist, um ein Steuersignal in Reaktion auf die hämodynamischen Indikatoren zu entwickeln,
   (c) eine Patiententherapieeinrichtung (120, 130, 140) einschließlich einer elektrischen Therapieeinrichtung, die wenigstens eine stimulierende Elektrode (11) zum Aufbringen von stimulierenden Impulsen auf das Herzgewebe in Reaktion auf das Steuersignal innerhalb, vorbestimmter Therapieoptionen aufweist, die von einem Arzt ausgewählt werden, um die Kontraktionsstärke des Herzens des Patienten derart zu erhöhen, daß während der Kontraktion die Herzleistung erhöht wird, und
   (d) eine Applikationseinrichtung (60), die mit der Patiententherapieeinrichtung (120, 130, 140) und der Signaleinrichtung (20, 60) gekoppelt ist, um das Steuersignal an der Patiententherapieeinrichtung (120, 130, 140) anzulegen, um den kontraktilen Zustand durch Erhöhung der Kontraktionsstärke des Herzens zu verändern.

2. Vorrichtung zum Anwenden einer Therapie bei einem Patienten nach Anspruch 1, **dadurch gekennzeichnet**, daß: die Therapieeinrichtung ein Arzneimittelinfusionssystem (166) enthält, um dem Patienten ein Arzneimittel als Funktion des Steuersignals zu verabreichen, um die Kontraktionsstärke des Herzens des Patienten zu erhöhen.

3. Vorrichtung nach Anspruch 1 oder 2, **dadurch gekennzeichnet**, wobei die intrakardiale Abtasteinrichtung eine Druckabtasteinrichtung (17) umfaßt, die betreibbar ist, um den Druck in wenigstens einer ventrikulären Kammer des Herzens abzutasten, und wobei die Signaleinrichtung (20, 60) betreibbar ist, um ein Drucksteuersignal zu entwickeln, das sich als Funktion des Drucks aufgrund des Schlagvorgangs des Herzens verändert, wobei die Applikationseinrichtung betreibbar ist, um das Drucksteuersignal an der Patiententherapieeinrichtung (130, 140, 166) anzulegen, um den kontraktilen Zustand durch Erhöhen der Kontraktionsstärke des Herzens zu verändern.

4. Vorrichtung nach Anspruch 1, 2 oder 3, wobei die intrakardiale Abtasteinrichtung eine interkardiale Impedanzabtasteinrichtung (13, 15) umfaßt, die betreibbar ist, um das ventrikuläre Volumen in wenigstens einer ventrikulären Kammer des Herzens abzutasten, wobei die Signaleinrichtung (20, 60) betreibbar ist, um ein Volumensteuersignal zu entwickeln, das sich als Funktion des ventrikulären Volumens verändert, und wobei die Applikationseinrichtung betreibbar ist, um das Volumensteuersignal an der Patiententherapieeinrichtung anzulegen, um den kontraktilen Zustand durch Erhöhen der Kontraktionsstärke des Herzens zu verändern.

5. Vorrichtung nach Anspruch 4, wobei die Signaleinrichtung (20, 60) eine Einrichtung (110) umfaßt, die betreibbar ist, um eine Ausstoßfraktion zu berechnen, wobei die Signaleinrichtung betreibbar ist, um ein Steuersignal zu entwickeln, das sich als Funktion der Ausstoßfraktion verändert, wobei die Applikationseinrichtung (60) ferner betreibbar ist, um an der Patiententherapieeinrichtung (130, 140) das Steuersignal anzulegen, das als Funktion der Ausstoßfraktion varriert, wobei die Ausstoßfraktion berechnet wird, indem ein zum Anzeigen des Schlagvolumens ausgewählter Steuersignalwert durch einen zum Anzeigen des enddiastolischen Volumens ausgewählten Steuersignalwert geteilt wird.

6. Vorrichtung nach Anspruch 4, wobei die Abtasteinrichtung (10) betreibbar ist, um die Herzrate abzutasten, wobei die Signaleinrichtung (20, 60) eine Einrichtung (64, 72, 76) zum Berechnen der Herzleistung enthält, wobei die Signaleinrichtung betreibbar ist, um ein Steuersignal zu entwickeln, das sich als Funktion der Herzleistung verändert, wobei die Applikationseinrichtung (60) betreibbar ist, um an der Patiententherapieeinrichtung oder dem Arzneimittelinfusionssystem das Steuersignal anzulegen, das als Funktion der Herzleistung variiert, wobei die Herzleistung als Produkt eines zum Anzeigen der abgetasteten Hersrate ausgewählten Steuersignalwerts und eines zum Anzeigen des

Schlagvolumens ausgewählten Steuersignalwerts berechnet wird.

7. Vorrichtung nach Anspruch 3, wobei die Signaleinrichtung (20, 60) eine Einrichtung (58) zum Erzeugen eines Zeitveränderungssignals umfaßt, das proportional zum Druck ist, der in einer Herzkammer aufgrund des Schlagvorganges des Herzens gemessen wird, eine Einrichtung (58) zum Extrahieren eines Modulationssignals aus dem Zeitveränderungssignal aufgrund der Druckänderungen in der Herzkammer, wobei die Signaleinrichtung (20, 60) betreibbar ist, um das Drucksteuersignal aus dem Modulationssignal zu entwickeln.

8. Vorrichtung nach Anspruch 4, wobei die Signaleinrichtung (20, 60) eine Einrichtung (48) zum Erzeugen eines Zeitveränderungssignals enthält, das proportional zur Impedanz ist, die in einer Herzkammer aufgrund des Schlagvorgangs des Herzens gemessen wird, eine Einrichtung (48) zum Extrahieren eines Modulationssignals aus dem Zeitveränderungssignal aufgrund von Impedanzänderungen in der Herzkammer, wobei die Signaleinrichtung (20, 60) betreibbar ist, um ein Impedanzsteuersignal aus dem Modulationssignal zu erzeugen und die Applikationseinrichtung betreibbar ist, um das Impedanzsteuersignal an der Patiententherapieeinrichtung (130, 140, 166) anzulegen, um den kontraktilen Zustand durch Erhöhen der Kontraktionsstärke des Herzens zu verändern.

9. Vorrichtung nach Anspruch 4, wenn dieser von Anspruch 3 abhängig ist, wobei die Signaleinrichtung (20, 60) einen Mikroprozessor (110) enthält, um die Fläche innerhalb einer Kurve zu berechnen, die durch Integration einer Aufzeichnung des Drucks als Funktion des ventrikulären Volumens als Indikator der Schlagarbeit erhalten wird, wobei die Signaleinrichtung betreibbar ist, um ein Schlagarbeitsteuersignal zu entwickeln, das sich als Funktion des Schlagarbeitindikators verändert, und wobei die Applikationseinrichtung betreibbar ist, um das Schlagarbeitsteuersignal an der Patiententherapieeinrichtung (130, 140, 166) anzulegen, um den kontraktilen Zustand zu verändern.

10. Vorrichtung nach Anspruch 4, wenn dieser von Anspruch 3 abhängig ist, wobei die Signaleinrichtung (20, 60) einen Mikroprozessor (110) enthält, um die Neigung einer Regressionslinie, die durch maximale, an der Endsystole des Herzzyklus aufgenommene Druck/Volumenpunkte hindurch gezeichnet wird, als Indikator der Ausstoßphasenkontraktilität zu berechnen, wobei die Signaleinrichtung betreibbar ist, um ein Ausstoßphasensteuersignal zu entwickeln, das sich als Funktion des Indikators der Ausstoßphasenkontraktilität verändert, und wobei die Applikationseinrichtung betreibbar ist, um das Ausstoßphasensteuersignal an der Patiententherapieeinrichtung (130, 140, 166) anzulegen, um den kontraktilen Zustand zu verändern.

11. Vorrichtung nach Anspruch 4, wenn dieser von Anspruch 3 abhängig ist, wobei die Signaleinrichtung einen Mikroprozessor (110) enthält, um eine Kurve, die sich aus einer Aufzeichnung eines minimalen diastolischen Drucks gegen das enddiastolische Volumen ergibt, als Indikator einer diastolischen Funktion zu berechnen, wobei die Signaleinrichtung betreibbar ist, um ein Steuersignal der diastolischen Funktion zu entwickeln, das sich als Funktion der Kurve verändert, und wobei die Applikationseinrichtung betreibbar ist, um das Steuersignal der diastolischen Funktion an der Patiententherapieeinrichtung (130, 140, 166) anzulegen, um den kontraktilen Zustand zu verändern.

12. Vorrichtung nach Anspruch 1, wobei die Patiententherapieeinrichtung ferner eine Einrichtung (132, 135) enthält, um die stimulierenden Impulse der Elektrode (11) am Herzen in einem vorbestimmten Muster anzulegen, um die Kontraktionsstärke des Herzens zu erhöhen, wobei das vorbestimmte Muster der stimulierenden Impulse ein Impulspaar enthält, welches das Liefern eines ersten Impulses umfaßt, der entweder intrinsisch oder getaktet ist, gefolgt von einer Verzögerung in einem Bereich von 140 bis 200 msec, anschließend das Liefern eines zweiten Impulses in der Form eines Schrittmacherimpulses, der dem rechten Ventrikel des Herzens zuführbar ist, um die Kontraktionsstärke des Herzens zu erhöhen.

13. Vorrichtung nach Anspruch 1, wobei die Patiententherapieeinrichtung ferner eine Einrichtung (132, 136) enthält, um die stimulierenden Impulse der stimulierenden Elektrode (11) am Herzen in einem vorbestimmten Muster anzulegen, um die Kontraktionsstärke des Herzens zu erhöhen, wobei das vorbestimmte Muster ein Muster von stimulierenden Schrittmacherimpulsen ist, die den Herzkammern zuführbar sind.

14. Vorrichtung nach Anspruch 13, wobei die Schrittmacherimpulse gleichzeitig lieferbar sind.

15. Vorrichtung nach Anspruch 13 oder 14, wobei das Muster biventrikular ist.

16. Vorrichtung nach Anspruch 1, wobei die Patiententherapieeinrichtung ferner eine Einrichtung (132, 137) enthält, um die stimulierenden Impulse von der stimulierenden Elektrode (11) an wenigstens einem Ort im Herzen in einem vorbestimmten Muster anzulegen, um die Kontraktionsstärke des Herzens zu erhöhen, wobei das vorbestimmte

Muster der stimulierenden Impulse ein Berstmuster enthält, welches das Liefern von 1 bis 12 stimulierenden Impulsen bei einer Frequenz im Bereich von 10 bis 130 Hz enthält.

17. Vorrichtung nach Anspruch 1, wobei die Patiententherapieeinrichtung ferner eine Einrichtung (132, 138) enthält, um die stimulierenden Impulse von der stimulierenden Elektrode (11) auf das Herz in einem vorbestimmten Muster aufzubringen, um die Kontraktionsstärke des Herzens zu erhöhen, wobei das vorbestimmte Muster der stimulierenden Impulse ein Muster eines eingeschobenen Schrittmachervorganges enthält, das wenigstens einen Extrastimulus umfaßt, der dem rechten Ventrikel zuführbar ist, eine Verzögerungseinrichtung (132) zum Berechnen einer Verzögerung eines voreingestellten Intervalls, nachdem das Steuersignal das Vorhandensein eines durchgeführten Herzschlags anzeigt, und eine Einrichtung (132) zum Entwickeln eines Steuersignals, um zu bewirken, daß die Patiententherapieeinrichtung wenigstens einen Extrastimulus dem rechten Ventrikel zuführt, wodurch eine Entspannungsperiode zwischen Herzschlägen verlängert wird, um die Kontraktionsstärke des Herzens zu erhöhen.

18. Vorrichtung nach Anspruch 1, wobei die Patiententherapieeinrichtung ferner eine Skelettmuskelstimulationseinrichtung (140) enthält, um ein vorbestimmtes Muster der stimulierenden Impulse von der stimulierenden Elektrode (11) auf einen Skelettmuskel (142) aufzubringen, der chirurgisch am Herzen befestigt worden ist, um die Kontraktionsstärke des Herzens zu erhöhen.

19. Vorrichtung nach Anspruch 1 oder 2, wobei die Einrichtung zum Anlegen des Steuersignals an der Patiententherapieeinrichtung (130, 140) ferner eine Telemetrieeinrichtung (160) zum Übertragen und Empfangen von radiofrequenzkodierten Signalen enthält.

**Revendications**

1. Appareil pour appliquer une thérapie à un patient, pour le traitement de problèmes cardiaques chroniques affectant la rigidité de la paroi, afin d'améliorer la contraction ou la relaxation de la paroi, la thérapie étant basée sur l'état contractile, tel qu'indiqué par les niveaux du volume et de la pression diastoliques finaux ventriculaires du coeur dudit patient, caractérisé en ce que l'appareil comprend :

   (a) un moyen de mesure intracardiaque (10) pour détecter des indicateurs hémodynamiques d'état contractile dans au moins une chambre ventriculaire du coeur, lesdits indicateurs hémodynamiques comprenant une mesure (76) du débit cardiaque du coeur ;
   (b) un moyen de signalisation (20, 60) couplé audit moyen de mesure (10) pour développer un signal de commande en réponse auxdits indicateurs hémodynamiques ;
   (c) un moyen de thérapie de patient (120, 130, 140), y compris des moyens d'électrothérapie, ayant au moins une électrode de stimulation (11) pour appliquer des impulsions de stimulation du tissu du coeur, en réponse audit signal de commande, selon des options de thérapie prédéterminées sélectionnées par un médecin, pour augmenter l'intensité de contraction du coeur du patient de manière à augmenter le débit cardiaque durant la contraction ; et
   (d) un moyen d'application (60) couplé au moyen de thérapie de patient (120, 130, 140) et au moyen de signalisation (20, 60), pour appliquer ledit signal de commande audit moyen de thérapie de patient (120, 130, 140), afin de modifier l'état contractile en augmentant l'intensité de contraction du coeur.

2. Appareil pour appliquer une thérapie à un patient selon la revendication 1, caractérisé en ce que :
   le moyen de thérapie comprend un système d'infusion de médicament (166) pour administrer un médicament au patient d'après ledit signal de commande, afin d'augmenter l'intensité de contraction du coeur du patient.

3. Appareil selon la revendication 1 ou 2, dans lequel ledit moyen de mesure intracardiaque comprend un moyen de mesure de pression (17) servant à mesurer la pression dans au moins une chambre ventriculaire du coeur et ledit moyen de signalisation (20, 60) sert à développer un signal de commande de pression variant d'après ladite pression, en raison de l'action de battement du coeur, ledit moyen d'application servant à appliquer ledit signal de commande de pression audit moyen de thérapie de patient (130, 140, 166) pour modifier ledit état contractile en augmentant l'intensité de contraction du coeur.

4. Appareil selon la revendication 1, 2 ou 3, dans lequel ledit moyen de mesure intracardiaque comprend un moyen de mesure impédance intracardiaque (13, 15) servant à mesurer le volume ventriculaire dans au moins une chambre ventriculaire du coeur ; ledit moyen de signalisation (20, 60) servant à développer un signal de commande de volume variant d'après ledit volume ventriculaire ; et ledit moyen d'application servant à appliquer ledit signal de commande de volume audit moyen de thérapie de patient pour modifier l'état contractile en augmentant l'intensité de contraction du coeur.

5. Appareil selon la revendication 4, dans lequel ledit moyen de signalisation (20, 60) comprend un moyen (110) servant à calculer une fraction d'éjection, ledit moyen de signalisation servant à développer un signal de commande variant d'après ladite fraction d'éjection, ledit moyen d'application (60) servant en outre à appliquer, audit moyen de thérapie de patient (130, 140), ledit signal de commande qui varie d'après une fraction d'éjection, dans lequel la fraction d'éjection est calculé en divisant une valeur de signal de commande sélectionnée pour indiquer le volume systolique par une valeur de signal de commande sélectionnée pour indiquer le volume diastolique final.

6. Appareil selon la revendication 4, dans lequel ledit moyen de mesure (10) sert à mesurer la fréquence cardiaque, ledit moyen de signalisation (20, 60) comprenant un moyen (64, 72, 76) pour calculer le débit cardiaque, ledit moyen de signalisation servant à développer un signal de commande variant d'après ledit débit cardiaque, ledit moyen d'application (60) servant à appliquer, audit moyen de thérapie de patient ou au système d'infusion de médicament, ledit signal de commande qui varie d'après le débit cardiaque, dans lequel le débit cardiaque est calculé comme le produit d'une valeur de signal de commande sélectionnée pour indiquer la fréquence cardiaque mesurée, par une valeur de signal de commande sélectionnée pour indiquer le volume systolique.

7. Dispositif selon la revendication 3, dans lequel ledit moyen de signalisation (20, 60) comprend un moyen (58) pour produire un signal de variation de temps proportionnel à la pression mesurée dans une chambre cardiaque, en raison de l'action de battement du coeur ; un moyen (58) pour extraire, dudit signal de variation de temps, un signal de modulation en raison de variations de pression dans ladite chambre cardiaque ; ledit moyen de signalisation (20, 60) servant à développer un signal de commande de pression à partir dudit signal de modulation.

8. Dispositif selon la revendication 4, dans lequel ledit moyen de signalisation (20, 60) comprend un moyen (48) pour produire un signal de variation de temps proportionnel à l'impédance mesurée dans une chambre cardiaque, en raison de l'action de battement du coeur ; un moyen (48) pour extraire, dudit signal de variation de temps, un signal de modulation en raison des variations d'impédance dans ladite chambre cardiaque ; ledit moyen de signalisation (20, 60) servant à produire un signal de commande d'impédance à partir dudit signal de modulation et ledit moyen d'application servant à appliquer ledit signal de commande d'impédance audit moyen de thérapie de patient (130, 140, 166), pour modifier l'état contractile en augmentant l'intensité de contraction du coeur.

9. Dispositif selon la revendication 4, en fonction de la revendication 3, dans lequel ledit moyen de signalisation (20, 60) comprend un microprocesseur (110) pour calculer l'aire à l'intérieur d'une courbe obtenue par intégration d'un graphique de la pression par rapport au volume ventriculaire, à titre d'indicateur du travail systolique ; ledit moyen de signalisation servant à développer un signal de commande de travail systolique variant d'après l'indicateur de travail systolique ; et ledit moyen d'application servant à appliquer ledit signal de commande de travail systolique audit moyen de thérapie de patient (130, 140, 166), pour modifier l'état contractile.

10. Dispositif selon la revendication 4, en fonction de la revendication 3, dans lequel ledit moyen de signalisation (20, 60) comprend un microprocesseur (110) pour calculer la pente d'une ligne de régression passant par les points de pression/volume maximaux pris a la fin du travail systolique du cycle cardiaque, à titre d'indicateur de la contractilité de phase d'éjection ; ledit moyen de signalisation servant à développer un signal de commande de phase d'éjection d'après l'indicateur de la contractilité de phase d'éjection ; et ledit moyen d'application servant à appliquer ledit signal de commande de phase d'éjection audit moyen de thérapie de patient (130, 140, 166), pour modifier ledit état contractile.

11. Dispositif selon la revendication 4, dépendant de la revendication 3, dans lequel ledit moyen de signalisation comprend un microprocesseur (110) pour calculer une courbe résultant d'un graphique de la pression diastolique minimale par rapport au volume diastolique final, à titre d'indicateur de la fonction diastolique ; ledit moyen de signalisation servant à développer un signal de commande de fonction diastolique variant en fonction de ladite courbe ; et ledit moyen d'application servant à appliquer ledit signal de commande diastolique audit moyen de thérapie de patient (130, 140, 166), pour modifier ledit état contractile.

12. Dispositif selon la revendication 1, dans lequel ledit moyen de thérapie de patient comprend en outre un moyen (132, 135) pour appliquer lesdites impulsions de stimulation provenant de ladite électrode (11) au coeur, selon un modèle prédéterminé, pour augmenter l'intensité de contraction dudit coeur, dans lequel ledit modèle prédéterminé d'impulsions de stimulation comprend un couple d'impulsions, ledit couple comprenant l'amenée d'une première impulsion qui est intrinsèque ou entraînée, suivie d'un retard compris dans une plage allant de 140 à 200 msec, puis l'amenée d'une deuxième impulsion se présentant sous la forme d'une impulsion

d'entraînement, pouvant être fournie au ventricule droit du coeur, pour augmenter l'intensité de contraction dudit coeur.

13. Dispositif selon la revendication 1, dans lequel ledit moyen de thérapie de patient comprend en outre un moyen (132, 136) pour appliquer lesdites impulsions de stimulation provenant de ladite électrode de stimulation (11) au coeur, selon un modèle prédéterminé, pour augmenter l'intensité de contraction dudit coeur, dans lequel ledit modèle prédéterminé est un modèle d'impulsions d'entraînement pouvant être fourni aux chambres du coeur.

14. Dispositif selon la revendication 13, dans lequel lesdites impulsions d'entraînement peuvent être fournies simultanément.

15. Dispositif selon la revendication 13 ou 14, dans lequel ledit modèle est biventriculaire.

16. Dispositif selon la revendication 1, dans lequel ledit moyen de thérapie de patient comprend en outre un moyen (132, 137) pour appliquer lesdites impulsions de stimulation provenant de ladite électrode de stimulation (11) à au moins un emplacement dans le coeur, selon un modèle prédéterminé, pour augmenter l'intensité de contraction dudit coeur, dans lequel ledit modèle prédéterminé desdites impulsions de stimulation comprend un modèle de salves, ledit modèle de salves comprenant l'amenée de 1 à 12 impulsions de stimulation à une fréquence comprise dans la plage allant de 10 à 130 Hz.

17. Dispositif selon la revendication 1, dans lequel ledit moyen de thérapie de patient comprend un moyen (132, 138) pour appliquer lesdites impulsions de stimulation provenant de ladite électrode de stimulation (11) au coeur, selon un modèle prédéterminé, pour augmenter l'intensité de contraction dudit coeur, dans lequel ledit modèle prédéterminé desdites impulsions de stimulation comprend un modèle d'entraînement intercalé, comportant au moins un extrastimulus pouvant être fourni au ventricule droit ; un moyen de retard (132) pour calculer un retard d'un intervalle prédéterminé, après que ledit signal de commande ait indiqué la présence d'un battement de coeur réalisé ; et un moyen (132) pour développer un signal de commande pour forcer ledit moyen de thérapie de patient à fournir au moins un extrastimulus au ventricule droit, prolongeant de ce fait une période de relaxation entre des battements du coeur, pour augmenter l'intensité de contraction dudit coeur.

18. Dispositif selon la revendication 1, ans lequel ledit moyen de thérapie de patient comprend en outre un moyen de stimulation de muscle squelettique (140) pour appliquer un modèle prédéterminé desdites impulsions de stimulation, provenant de ladite électrode de stimulation (11), à un muscle squelettique (142) qui a été fixé chirurgicalement au coeur, pour augmenter l'intensité de contraction dudit coeur.

19. Dispositif selon la revendication 1 ou 2, dans lequel ledit moyen pour appliquer ledit signal de commande audit moyen de thérapie de patient (130, 140) comprend en outre un moyen de télémétrie (160) pour transmettre et recevoir des signaux codés de radiofréquence.

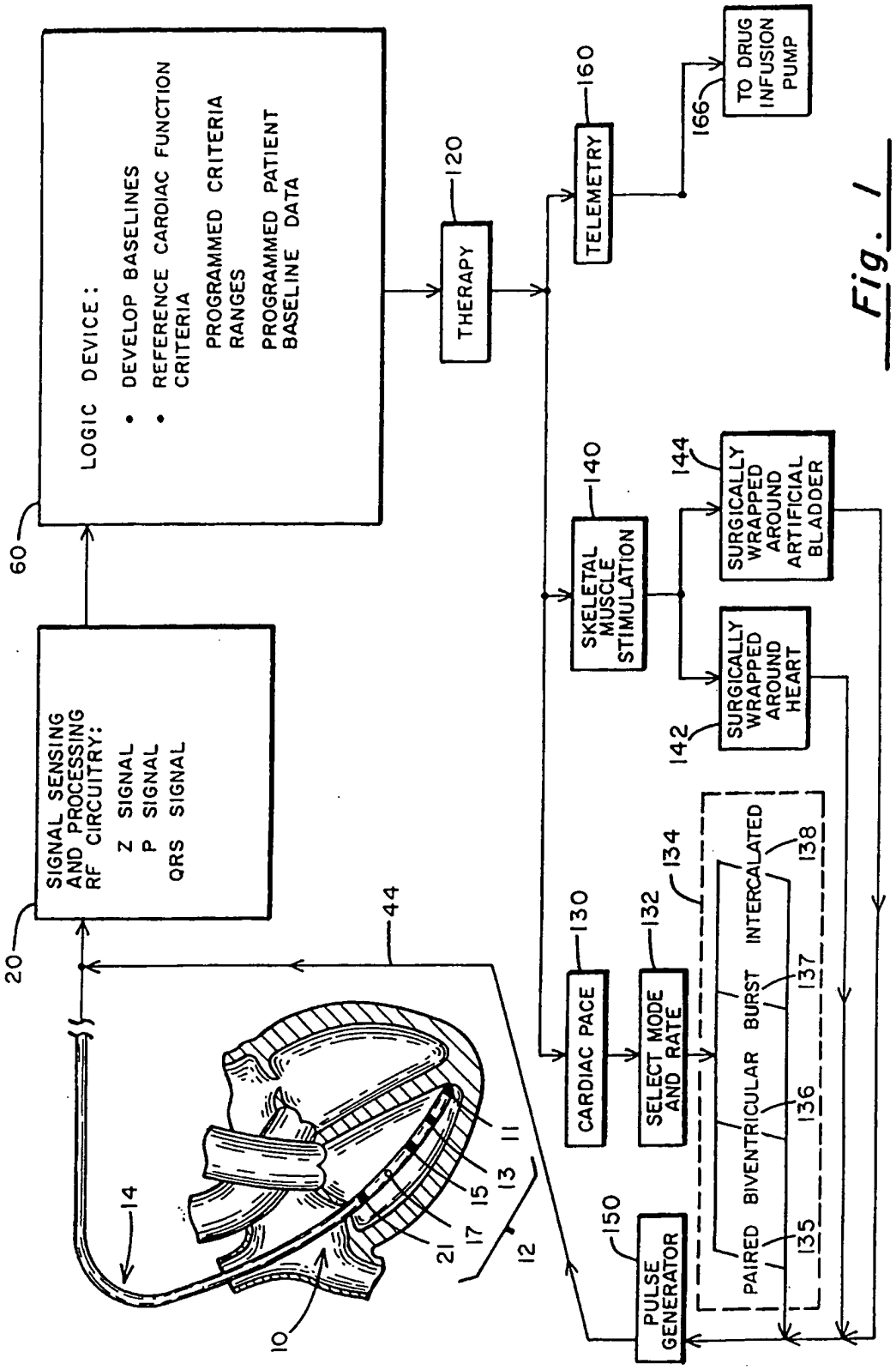
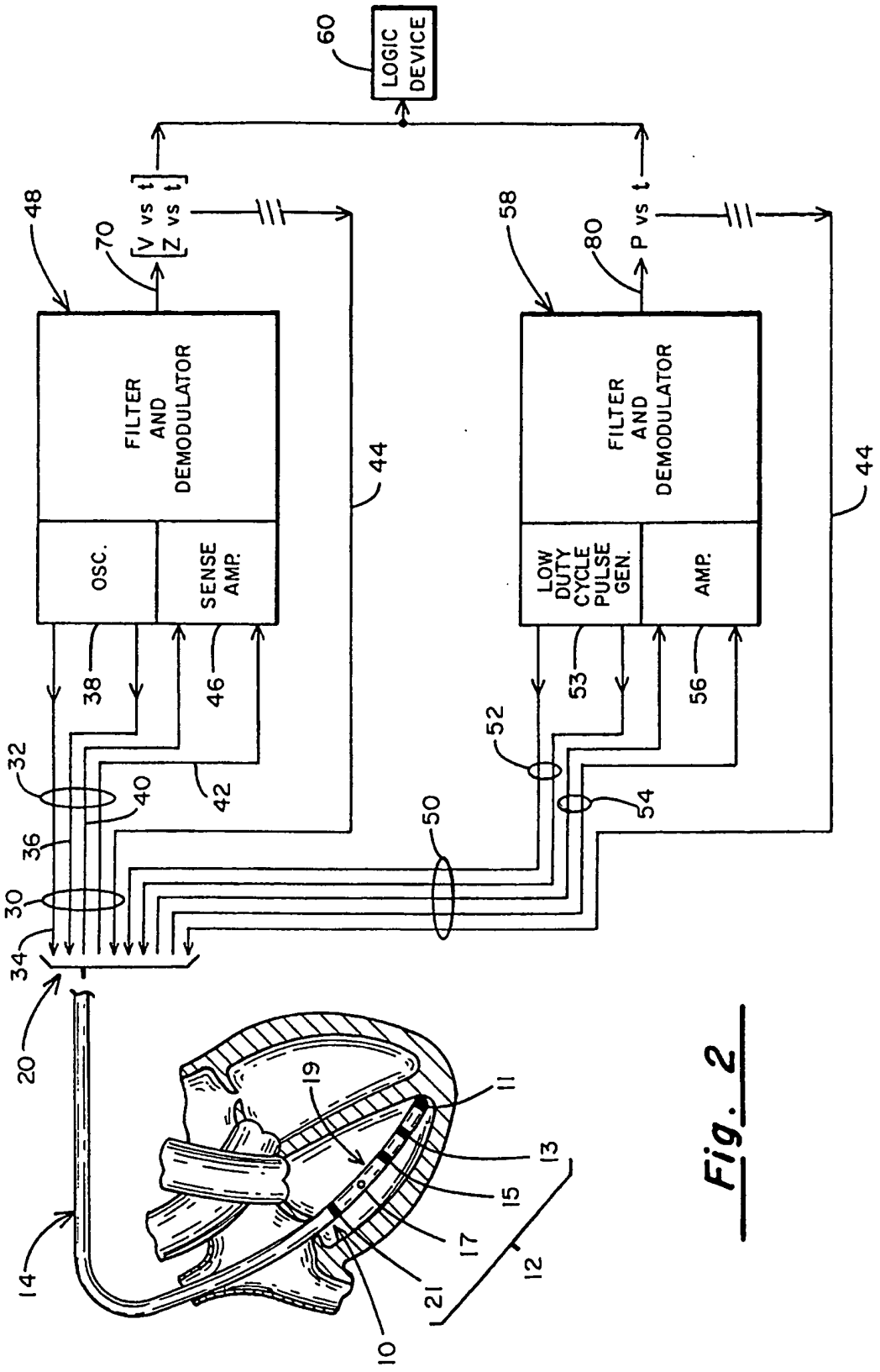

LOGIC DEVICE:
• DEVELOP BASELINES
• REFERENCE CARDIAC FUNCTION CRITERIA
PROGRAMMED CRITERIA RANGES
PROGRAMMED PATIENT BASELINE DATA
60
SIGNAL SENSING AND PROCESSING RF CIRCUITRY:
Z SIGNAL
P SIGNAL
QRS SIGNAL
20
THERAPY
120
TELEMETRY
160
166
TO DRUG INFUSION PUMP
SKELETAL MUSCLE STIMULATION
140
144
SURGICALLY WRAPPED AROUND ARTIFICIAL BLADDER
142
SURGICALLY WRAPPED AROUND HEART
CARDIAC PACE
130
SELECT MODE AND RATE
132
134
138
INTERCALATED BURST
137
136
BIVENTRICULAR
PAIRED
135
PULSE GENERATOR
150
44
14
10
21
17
15
13
11
12

Fig. 1


60
LOGIC DEVICE
48
70
V vs t
Z vs t
58
80
P vs t
FILTER AND DEMODULATOR
OSC.
SENSE AMP.
FILTER AND DEMODULATOR
LOW DUTY CYCLE PULSE GEN.
AMP.
44
44
38
46
53
56
32
40
42
52
54
36
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30
34
20
14
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19
11
13
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17
21
12

Fig. 2

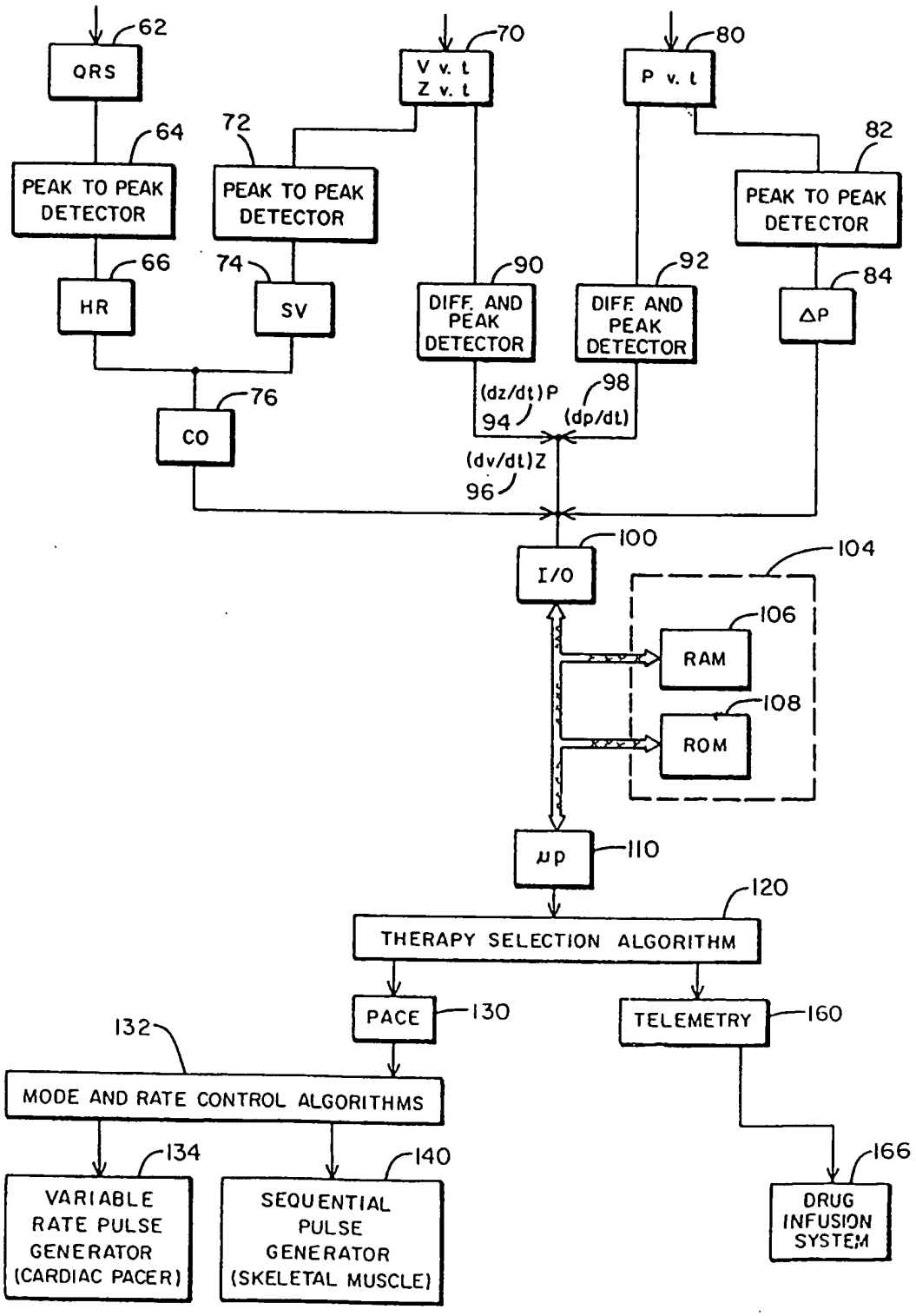
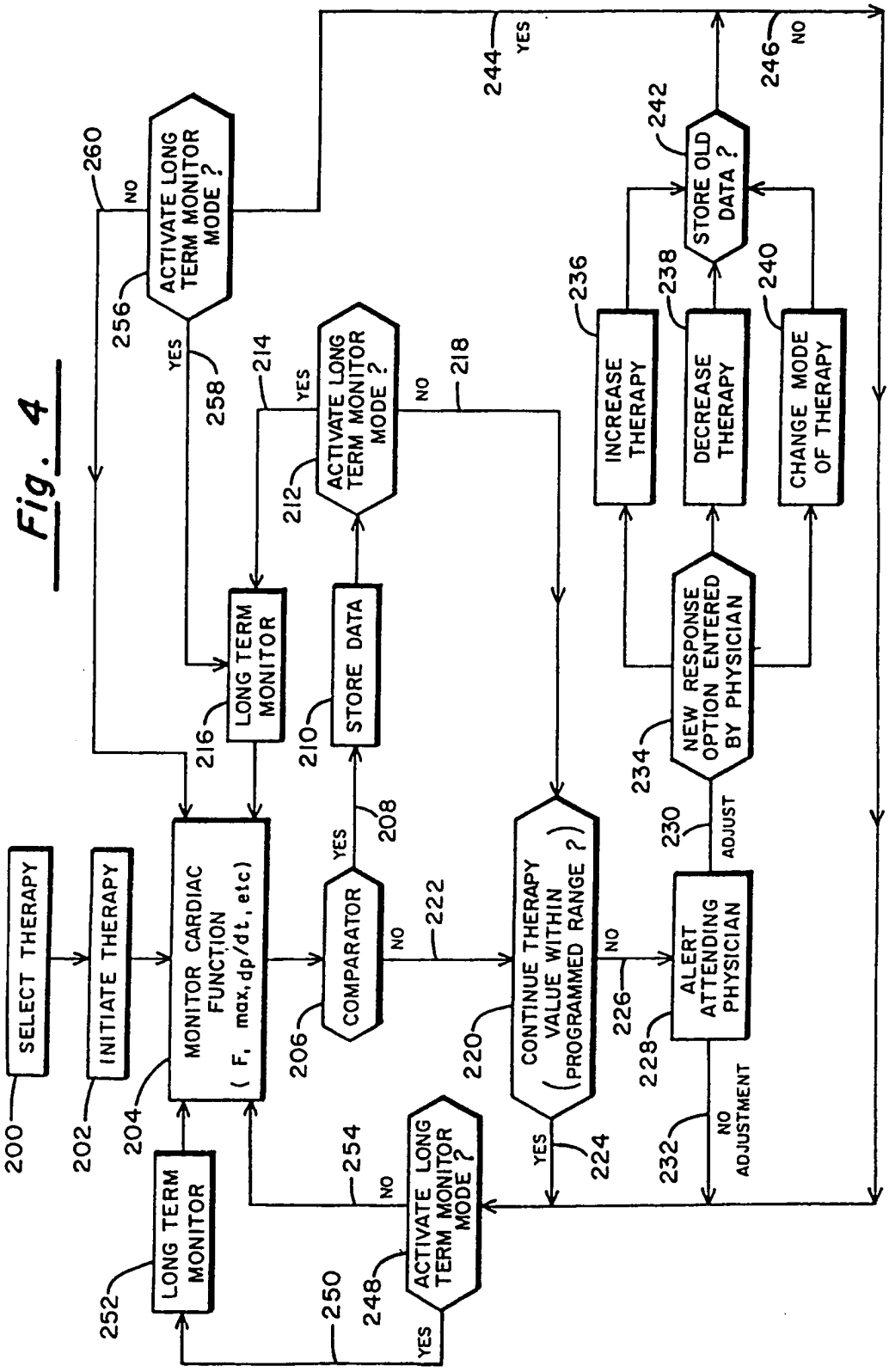

62
QRS
64
PEAK TO PEAK DETECTOR
66
HR
72
PEAK TO PEAK DETECTOR
74
SV
76
CO
70
V v. t
Z v. t
90
DIFF. AND PEAK DETECTOR
(dz/dt)P
94
(dv/dt)Z
96
80
P v. t
92
DIFF. AND PEAK DETECTOR
98
(dp/dt)
82
PEAK TO PEAK DETECTOR
84
ΔP
100
I/O
104
106
RAM
108
ROM
μp
110
120
THERAPY SELECTION ALGORITHM
PACE
130
TELEMETRY
160
132
MODE AND RATE CONTROL ALGORITHMS
134
VARIABLE RATE PULSE GENERATOR (CARDIAC PACER)
140
SEQUENTIAL PULSE GENERATOR (SKELETAL MUSCLE)
166
DRUG INFUSION SYSTEM

Fig. 3

Fig. 4


SELECT THERAPY
INITIATE THERAPY
MONITOR CARDIAC FUNCTION ( F, max, dp/dt, etc)
COMPARATOR
YES
NO
STORE DATA
LONG TERM MONITOR
ACTIVATE LONG TERM MONITOR MODE ?
CONTINUE THERAPY VALUE WITHIN (PROGRAMMED RANGE ?)
ALERT ATTENDING PHYSICIAN
NO ADJUSTMENT
ADJUST
NEW RESPONSE OPTION ENTERED BY PHYSICIAN
INCREASE THERAPY
DECREASE THERAPY
CHANGE MODE OF THERAPY
STORE OLD DATA ?
200
202
204
206
208
210
212
214
216
218
220
222
224
226
228
230
232
234
236
238
240
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258
260